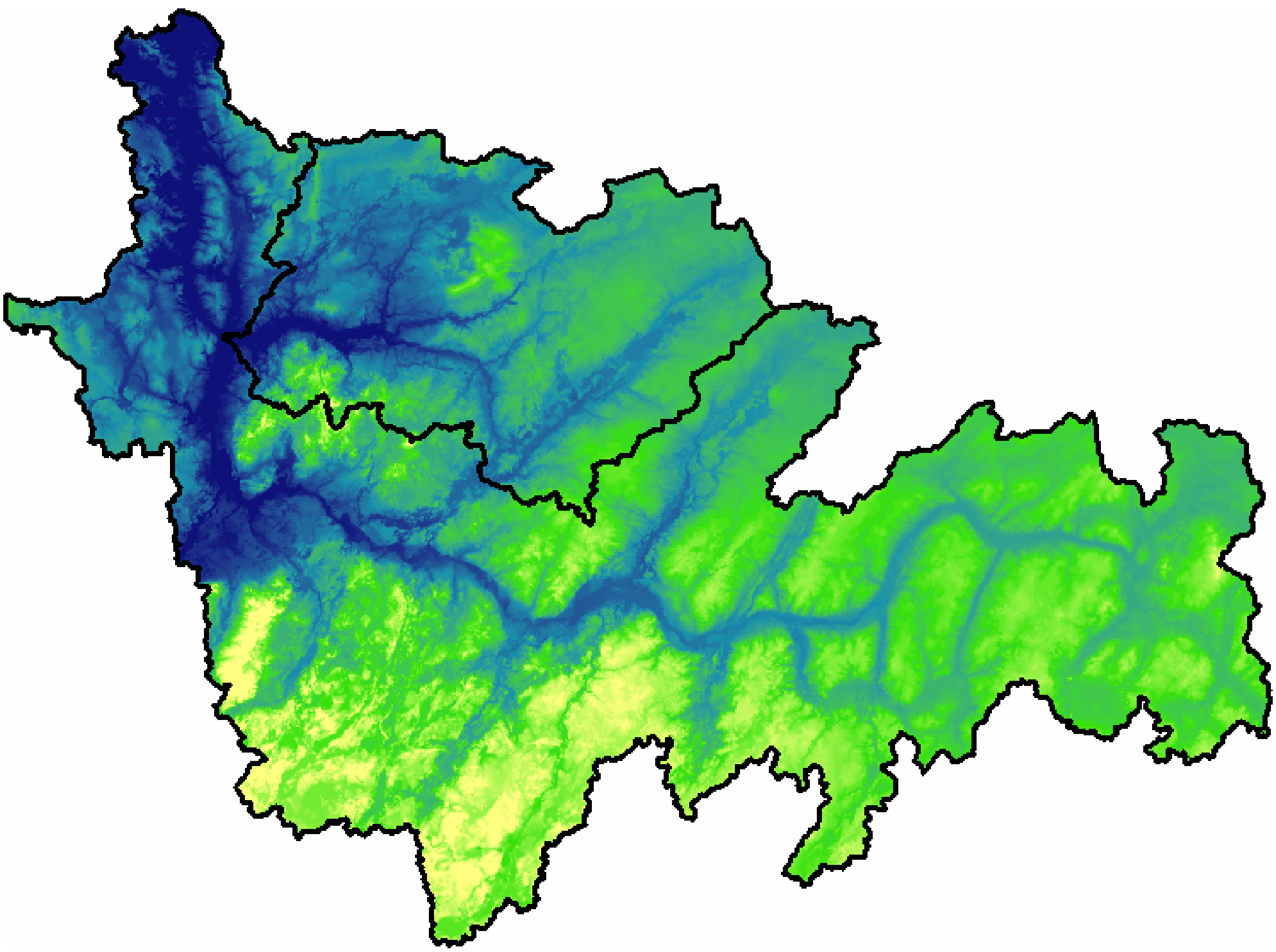
Thornapple River Watershed Flashiness Report



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DEQ Michigan's Nonpoint Source Program

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The cover depicts the ground elevations of the Thornapple River Watershed. Lighter colors are higher elevations.

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Watershed Overview

The Grand River watershed drains 5,566 square miles, Figure 1. The Lower Grand River Watershed Management Plan covers the lower 2,983 square miles. Some watersheds covered by the Lower Grand River Watershed Plan have elected to develop more detailed watershed plans.

One such watershed is the Thornapple River watershed. The Thornapple River drains 848 square miles. For planning purposes, however, the Thornapple River Watershed Management Plan excludes the Coldwater River watershed because the Coldwater has its own detailed watershed plan. The Thornapple River watershed, without the Coldwater River watershed, encompasses 660 square miles. The river outlets to the Grand River near the Village of Ada in Kent County.

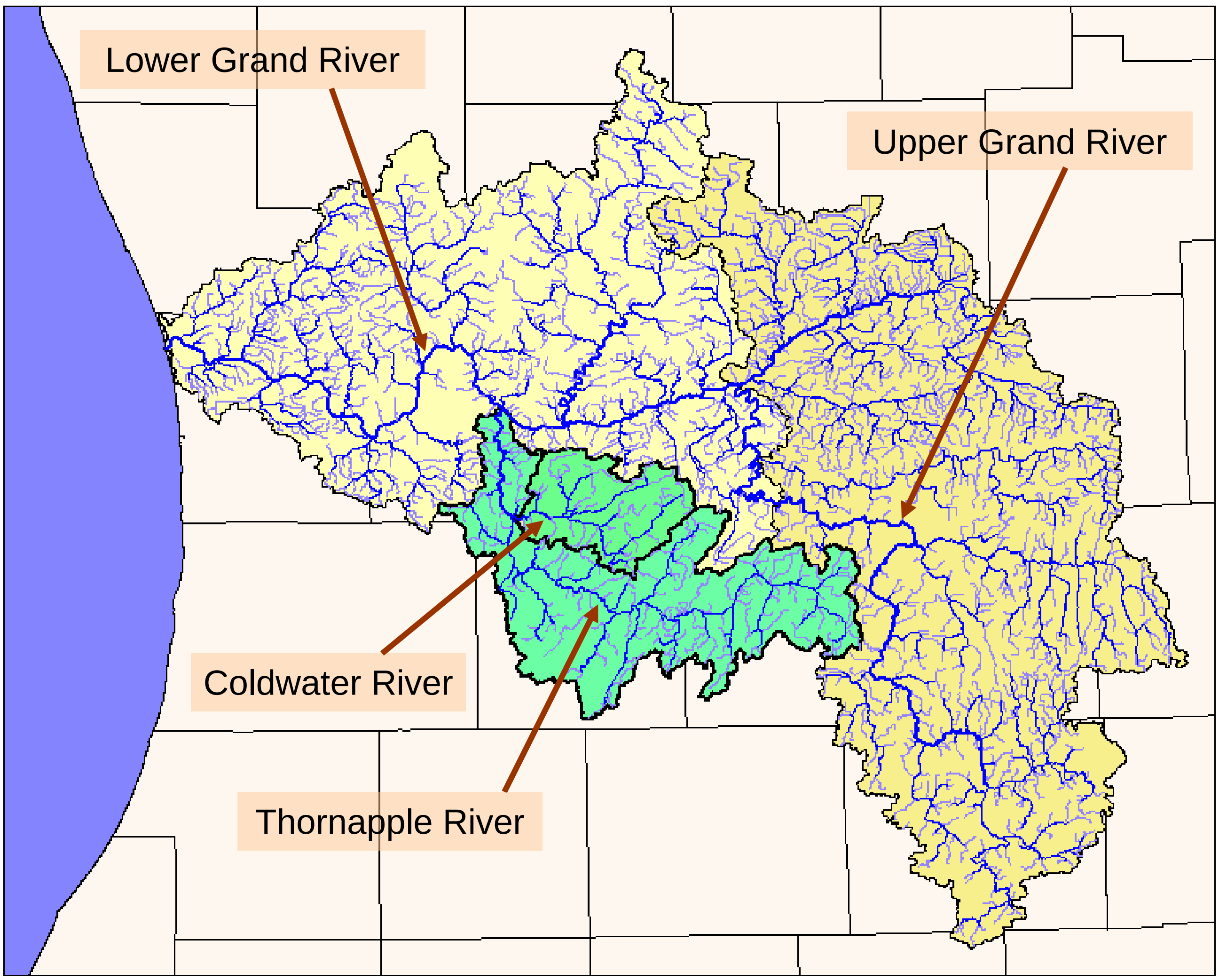


Figure 1 – Watershed Delineations

Flashiness

The term flashiness reflects the frequency and rapidity of short term changes in stream flow (Baker et al, 2004). A stream described as flashy responds to rainfall by rising and falling quickly. Conversely, a stream that is not flashy would rise and fall less for an equivalent rainfall and would typically derive more of its overall flow from groundwater. An increase in flashiness is a common cause of stream channel instability. In general, flashiness changes result from hydrologic alterations. Some factors that can alter flashiness include:

- In-Stream Changes
  - Removal or change in operation of a dam
  - Expansion or straightening of the drainage network
- Watershed Land Use Changes
  - Urbanization
  - Forest regrowth
  - Soil compaction
  - Change in paved or other impervious areas
  - Use of low impact development (LID) techniques
  - Change in forestry practices
  - Change in agricultural practices
  - Change in runoff storage capacity

Relatively modest, but frequent, storm events, such as the 50 percent chance (2-year) storm, have more effect on channel form than extreme flood flows. Unless properly managed, increases in runoff from 1- to 2-year storms increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows.

Land Use Changes

Land use change alters the hydrologic characteristics of the watershed and is the most common cause of runoff volume and flow changes. In the 1800’s and early 1900’s, the dominant land use change was the conversion of forest to agriculture, Figure 2. The dominant land use change now is urbanization, a process projected to continue by the Michigan Land Use Leadership Council (2003), Figure 3. These changes in the Thornapple River watershed are further detailed in Figure 4.

Land use changes that increase stormwater storage or infiltration decrease runoff volumes and peak flows. Other changes, especially those that reduce vegetative cover, often increase runoff and, consequently, flashiness. In particular, urbanization is frequently associated with increased runoff and flashiness, though effective stormwater management can minimize these effects.

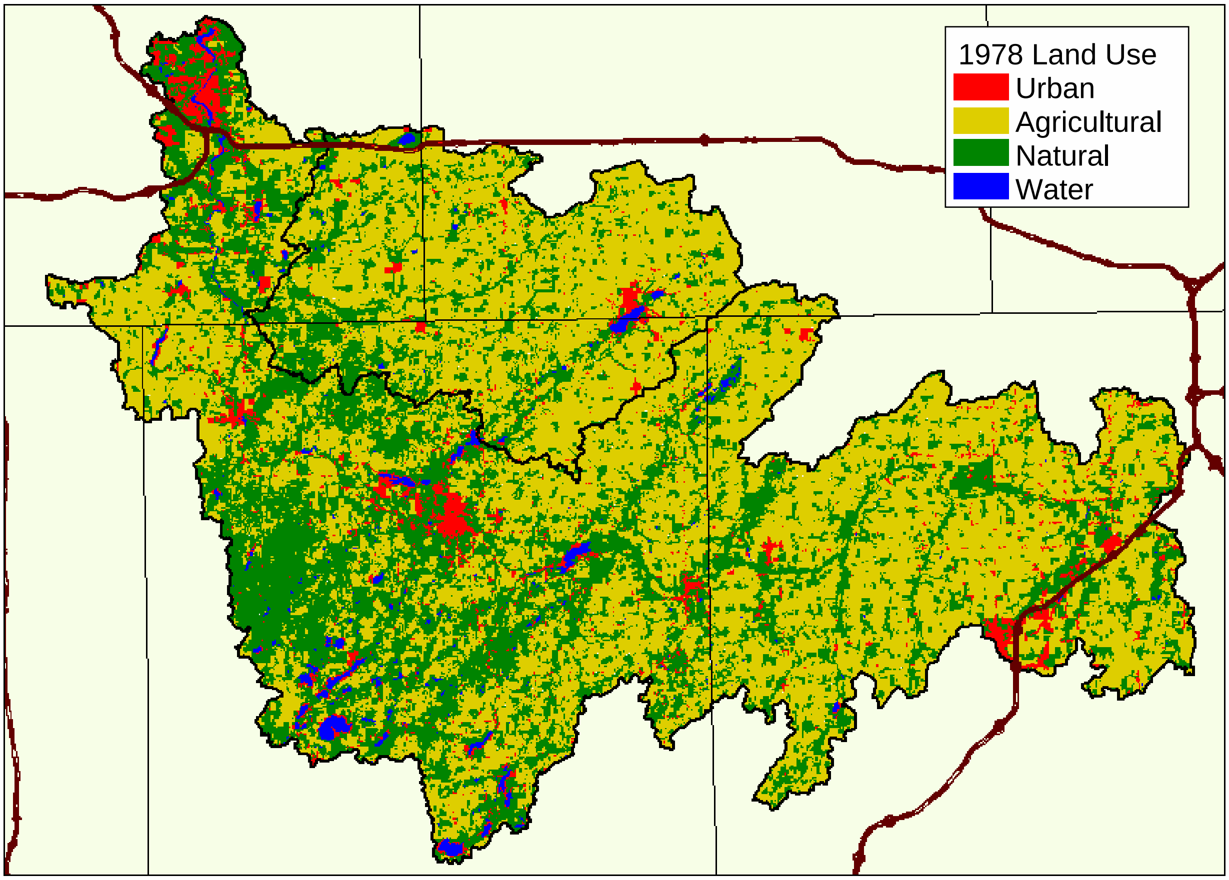


Figure 2 – 1978 Land Cover (Michigan Resource Information System)

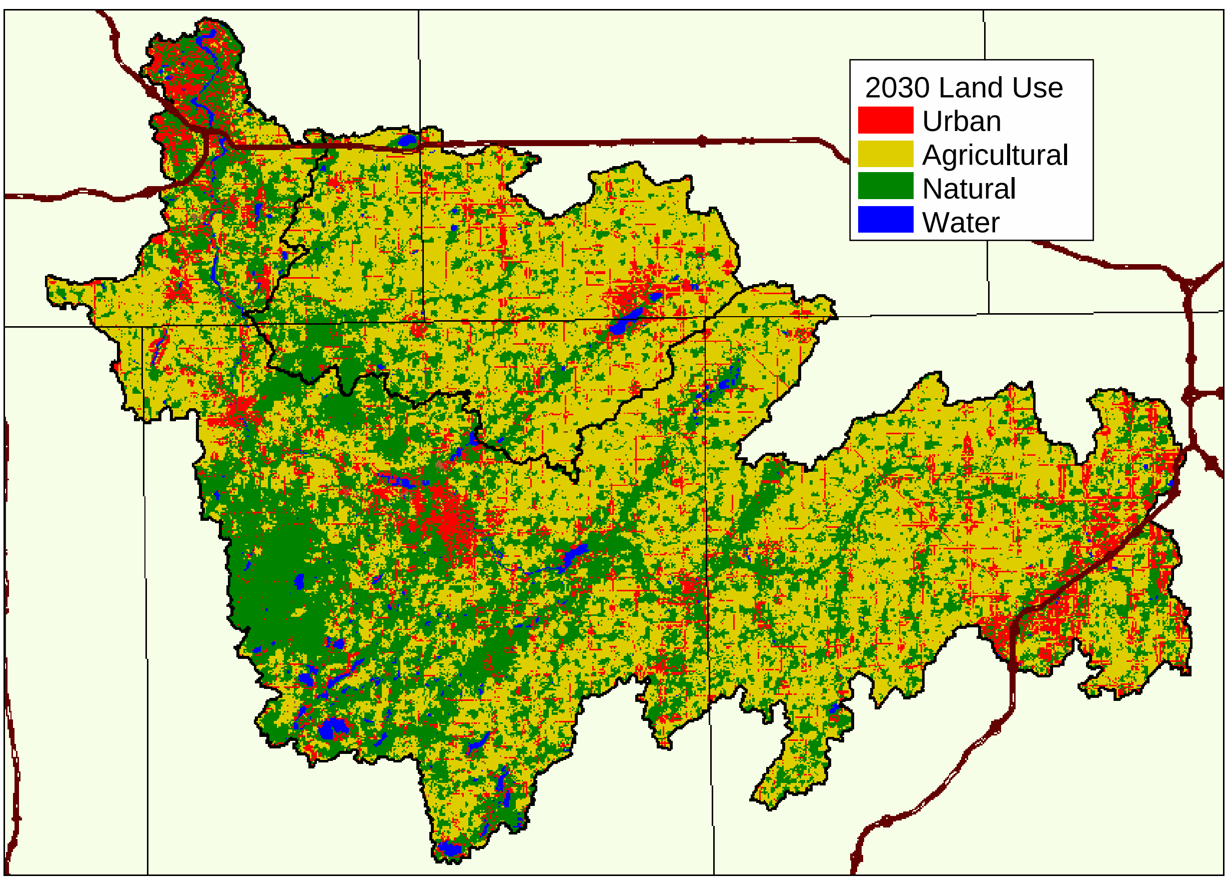


Figure 3 – 2030 Land Cover (Michigan Land Use Leadership Council final report)

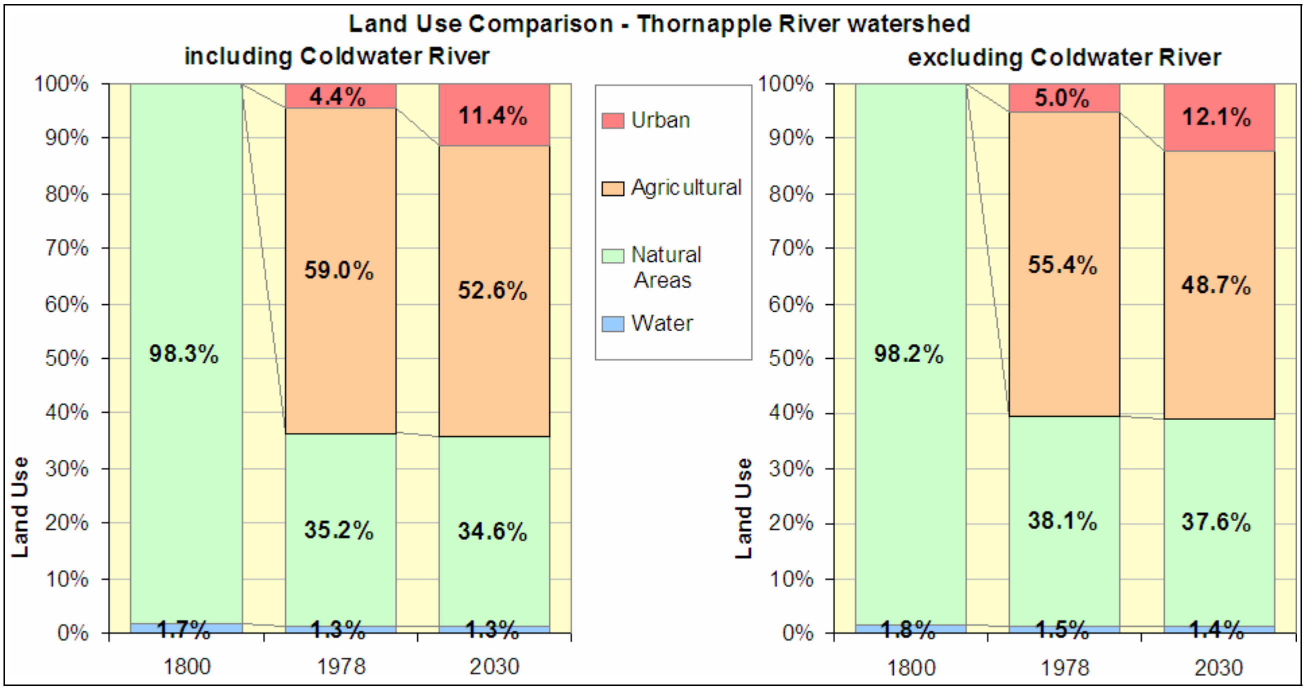


Figure 4 – Thornapple River Watershed Land Cover Comparison

Richards-Baker Flashiness Index

One approach to quantifying flashiness was proposed by Baker et al (2004). The method measures the path length of flow oscillations for data from gaged streams. Longer paths correlate with flashier streams, while more constant flows have shorter path lengths. Values for the R-B Index could theoretically range from zero to two. It would have a value of zero if the stream flow were absolutely constant. Its value increases as the path length, and therefore flashiness, increases. The Lower Rouge River hydrograph, Figure 5, illustrates the longer flow path associated with a flashy stream. The Au Sable River hydrograph illustrates the shorter flow path associated with more constant flows.

The R-B Index is one tool for diagnosing the scale of a particular stream channel problem. If the R-B Index values are steady over time, channel erosion problems in the vicinity of the USGS gage may have local, small-scale causes (e.g., cattle access) that can be addressed with a local BMP (e.g., fencing). Conversely, if the R-B Index trend indicates that flashiness is increasing over time, channel erosion problems in the vicinity of the gage station may have large scale causes (e.g., a watershed-wide increase in impervious area) and will require a large scale solution (e.g., regional stormwater management practices). Note that “in the vicinity of the gage” is not well defined. Streams that are increasingly flashy at one location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage. Similarly, flashy flows in a stream above the gage may be masked by the combined flows of other streams at the gage.

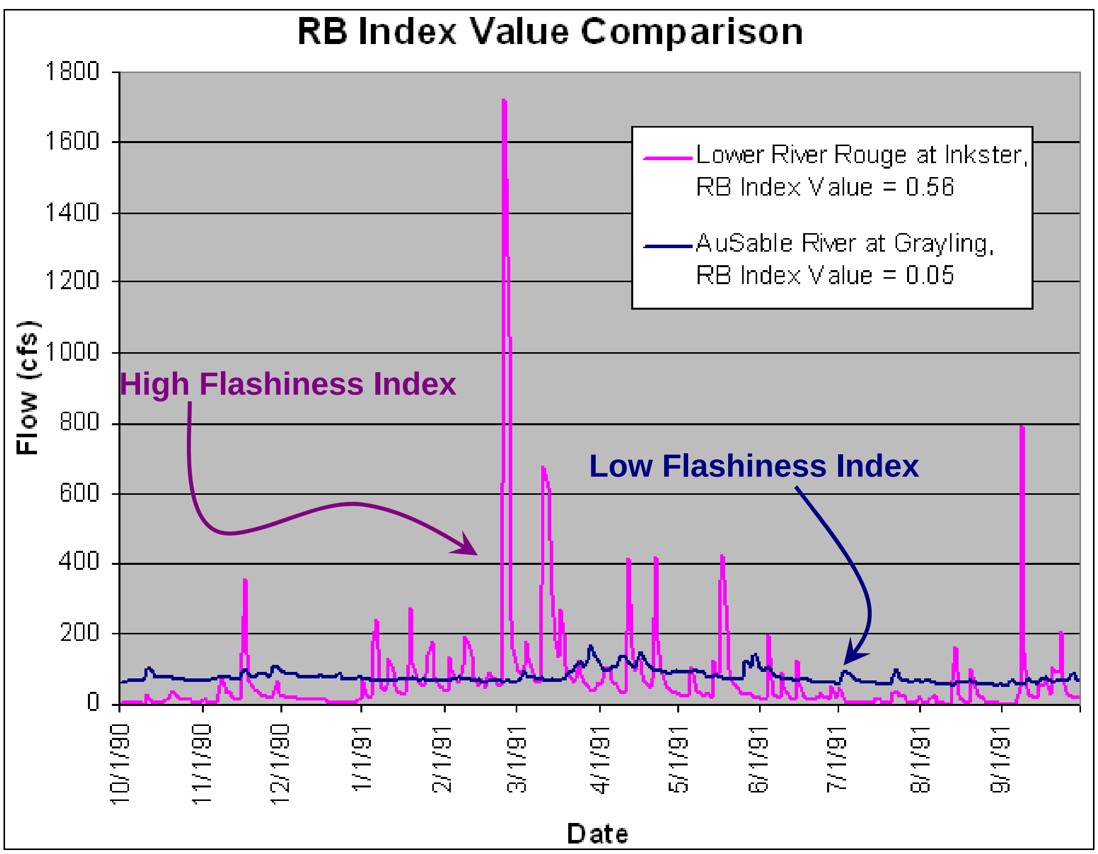


Figure 5 – Hydrographs for Two Michigan Streams

Quartile Ranking

MDEQ's NPS staff calculated yearly averaged R-B Index values and assessed trends for 279 USGS gages in Michigan that had at least five years of data through the end of water year 2004 (Fongers, 2007). The R-B Index values for Michigan ranged from 0.006 to 1.009, Figure 6. Quartile rankings are grouped by watershed size because of the natural tendency for flashiness to decrease as the drainage area increases. As watershed size increases, the varied timing of tributary flows help attenuate main channel peak flow and soils and land uses tend to diversify.

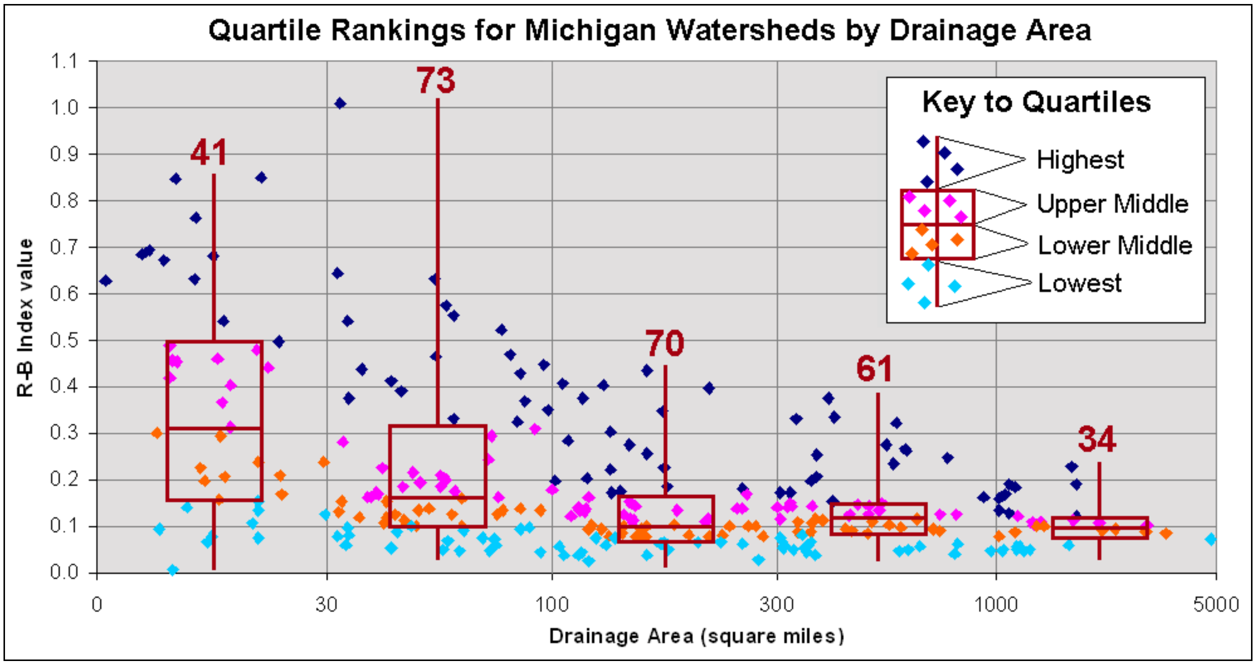


Figure 6 – Summary and Ranking of the R-B Index Values for 279 Michigan Gages

The yearly averaged R-B Index values for the Thornapple River watershed range from 0.109 to 0.300, with all gages in the uppermost quartile on a statewide basis. In itself, a high or low ranking is not necessarily good or bad. Rankings for Saginaw Bay area gages tend to be high at least partly because of the soils in that area, for example. The gage rankings in the Thornapple River watershed are typical of other gages in southwest lower Michigan, Figure 7, which generally are in the lower half of the rankings. In some cases, the relative rankings of watershed gages may be used to identify areas where methods to reduce flashiness can be employed, or to identify areas where extra effort is warranted to protect our most sensitive and exceptional streams. For the Thornapple River watershed, however, all of the gages, Figure 8 and Table 1, are in the lower middle quartile.

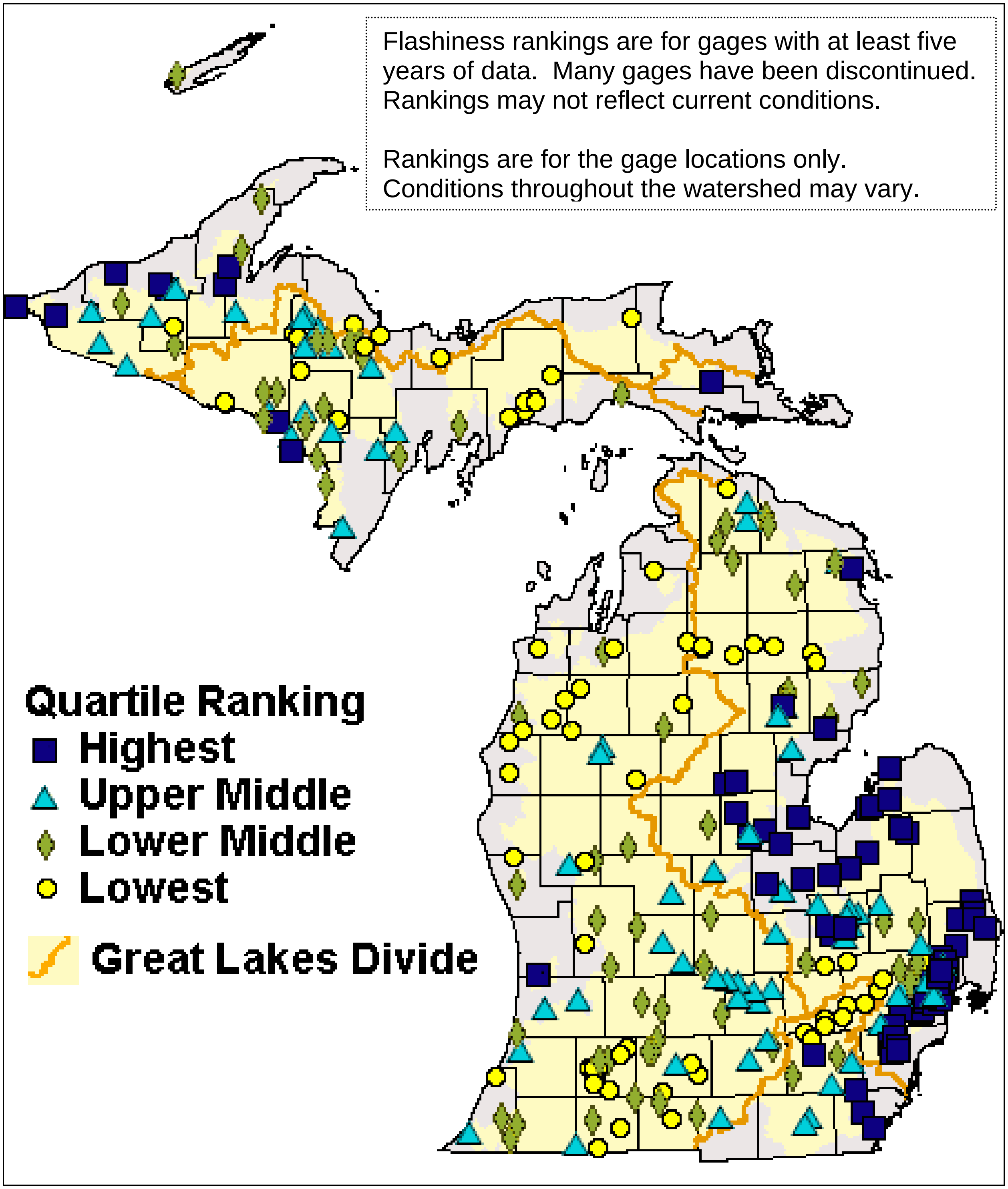


Figure 7 – Quartile Rankings, Michigan Watersheds

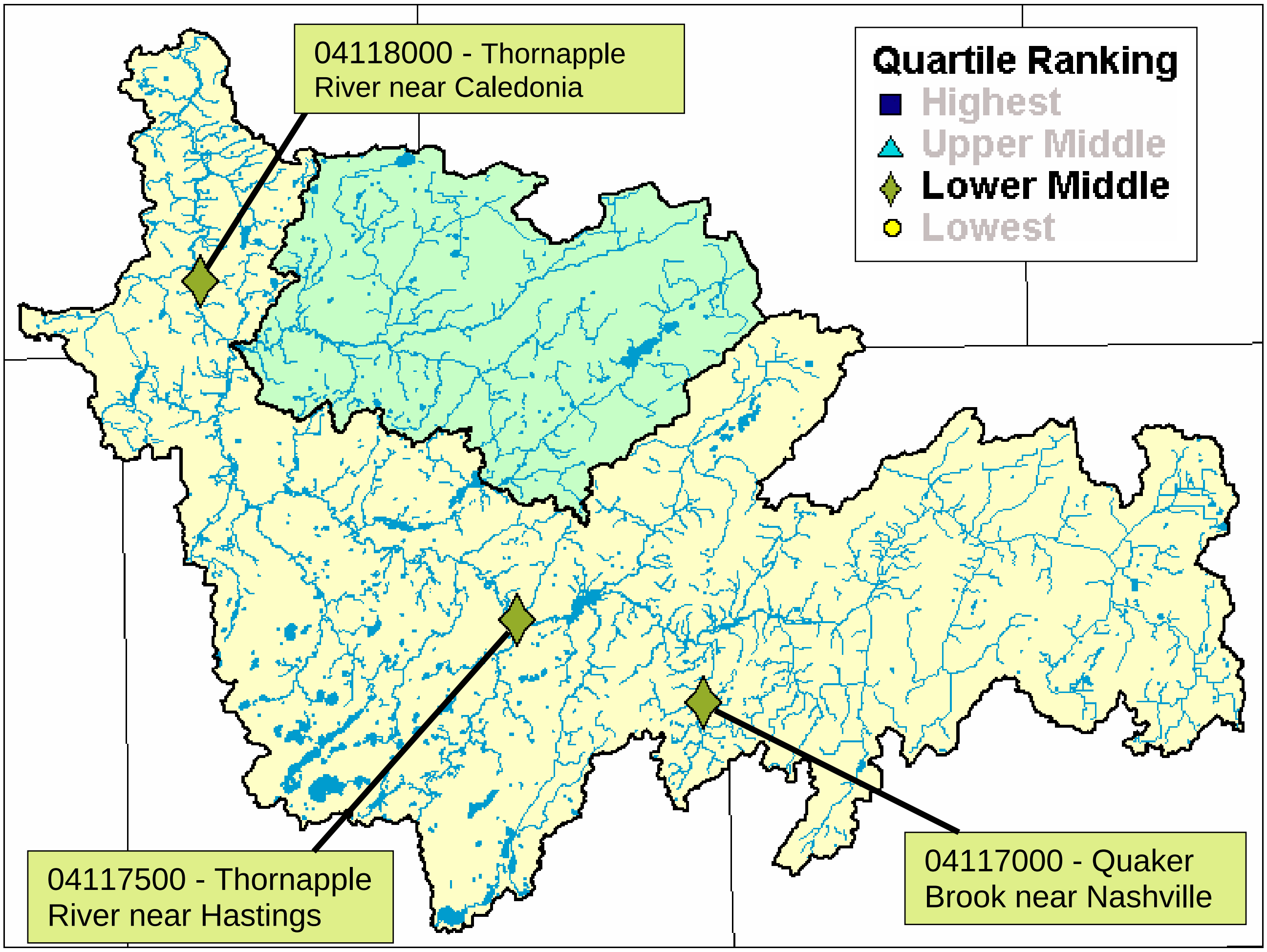


Figure 8 – Quartile Rankings, Thornapple River Watershed

Table 1 – Thornapple River Watershed Flashiness Results

Gage Number and Description	Total Drainage Area (sq. mi.)	Quartile Rank	Flashiness Trend
4117000: Quaker Brook near Nashville	8	lower middle	
4117500: Thornapple River near Hastings	410	lower middle	
4118000: Thornapple River near Caledonia	795	lower middle	more flashy

Trends

Fluctuations over time are apparent in a stream's R-B Index values. Some fluctuations in the R-B Index values are expected from year to year simply because of natural weather variations. Longer term trends result from hydrologic alterations within the watershed. Increasing flashiness stemming from higher peak flows or more frequent bankfull flows can result in changes to the channel shape: width, depth, sinuosity, and slope. These changes occur by erosion. This is especially true for stream channels that are steep and composed of noncohesive materials (Rhoads et al, 1991). Changes in stream channel shape, in turn, can have significant impacts on aquatic organism populations (Richards et al, 1997; Van Steeter et al, 1998). Because a stream can take 50 years or more to adapt to flow changes (Article 19 in Schueler, 2000), we restricted the trend analysis to gages in operation during the past 25 years. Consequently, any identified trends should be influencing the streams' morphology today.

The trends were based in part on visual examination of each gage's data, with linear regression used to objectively verify statistical significance. The linear trend lines shown in Figures 12 though 14 do not guarantee a linear relationship between flashiness and time for those streams, nor can they be used to predict future flashiness trends for those streams. The physical processes causing the changes are undoubtedly more complex. The trends identified are only intended to highlight streams experiencing flow changes that may physically alter the stream's channel morphology.

Statewide, 30 of the 210 gages in operation during the past 25 years have statistically significant decreasing trends and 41 of the gages have increasing trends, Figure 9. Many, but not all, are located near urban areas, Figure 10. This is expected because stream flow is the stream's response to many factors in a complex system - the watershed. Conversion of forest to cropland, reforestation of cropland, or a change in logging practices can have as much impact on streamflow as the transition from cropland to urban land uses. Nevertheless, urbanization, or more specifically imperviousness, has been undeniably linked with increased flashiness. When wise stormwater management is employed, adverse stream impacts can be minimized.

For the Thornapple River watershed gages, only one of the three gages has an increasing trend, Table 1 and Figure 11. The increasing flashiness trend of that gage, USGS #04118000 – Thornapple River near Caledonia, appears to be the result of the operation of a power plant.

The R-B Index values and trends apply only to the stream in the vicinity of the gage. Conditions at other locations in the watershed may vary. For example, flashy flows in a stream above a gage may be masked by the combined flows of other streams at the gage. Similarly, streams that are increasingly flashy at one gaged location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage.

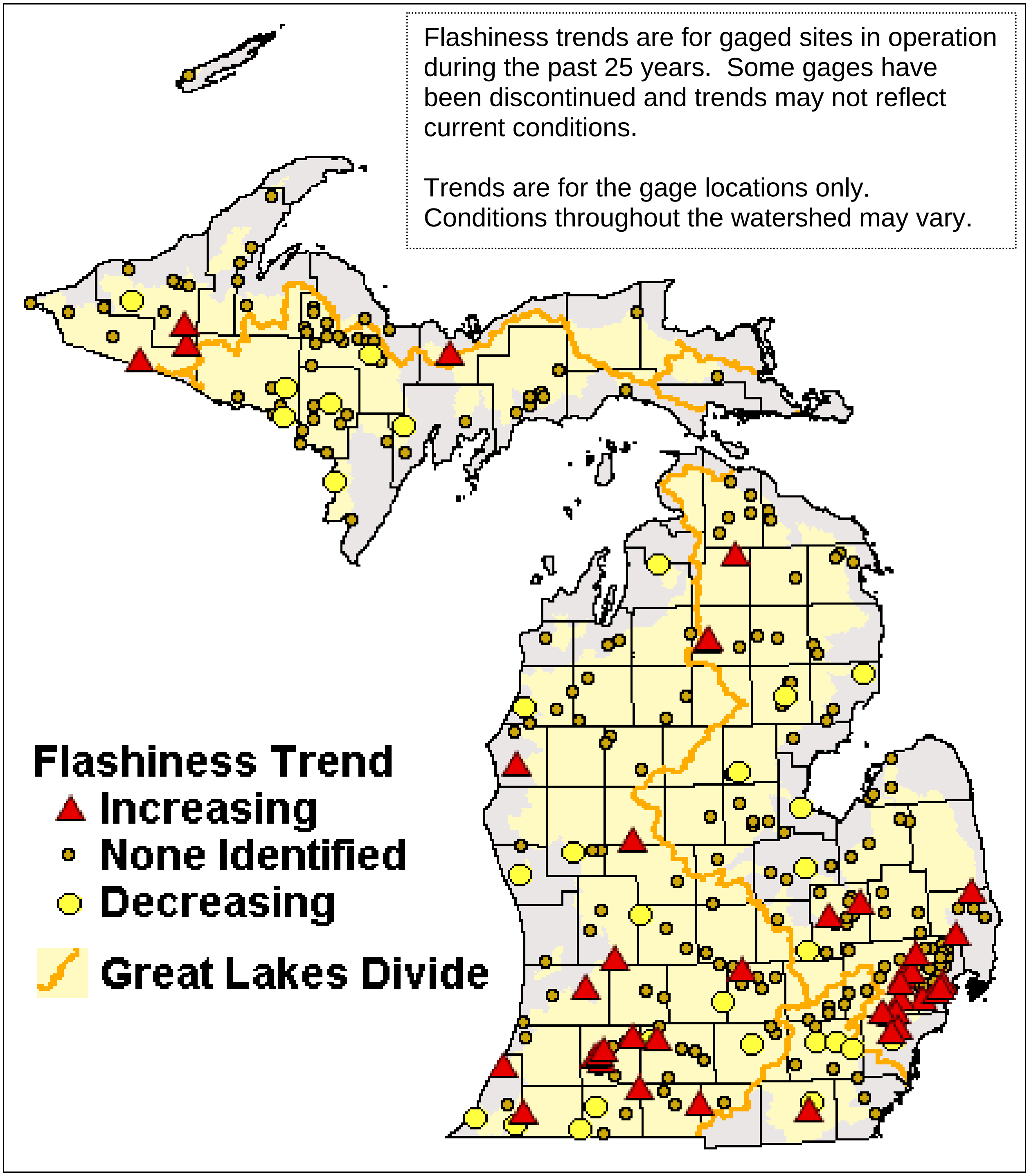


Figure 9 – Flashiness Trend by Gage, Michigan Watersheds

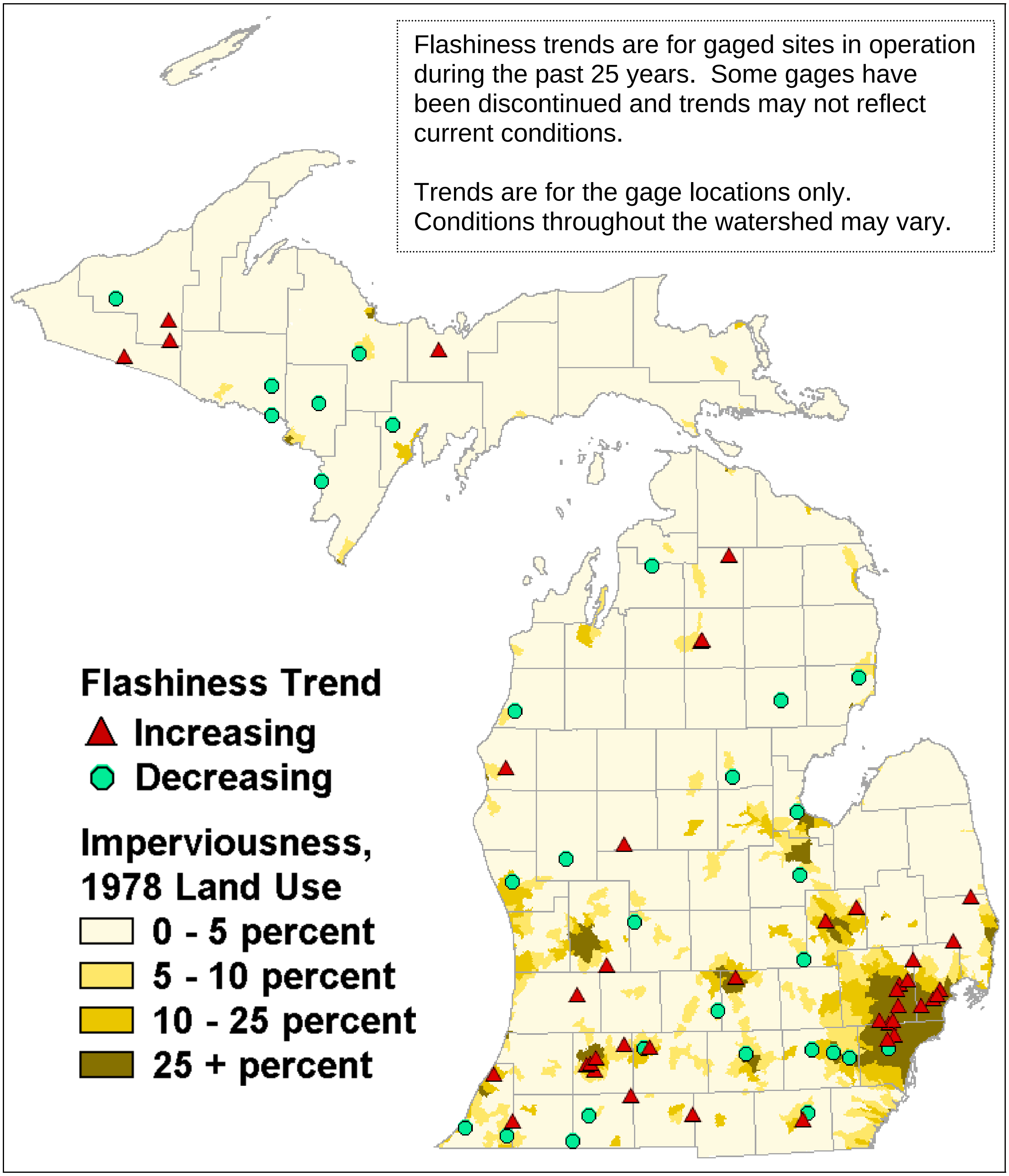


Figure 10 – Statewide Imperviousness with Flashiness Trends, 1978 Land Use

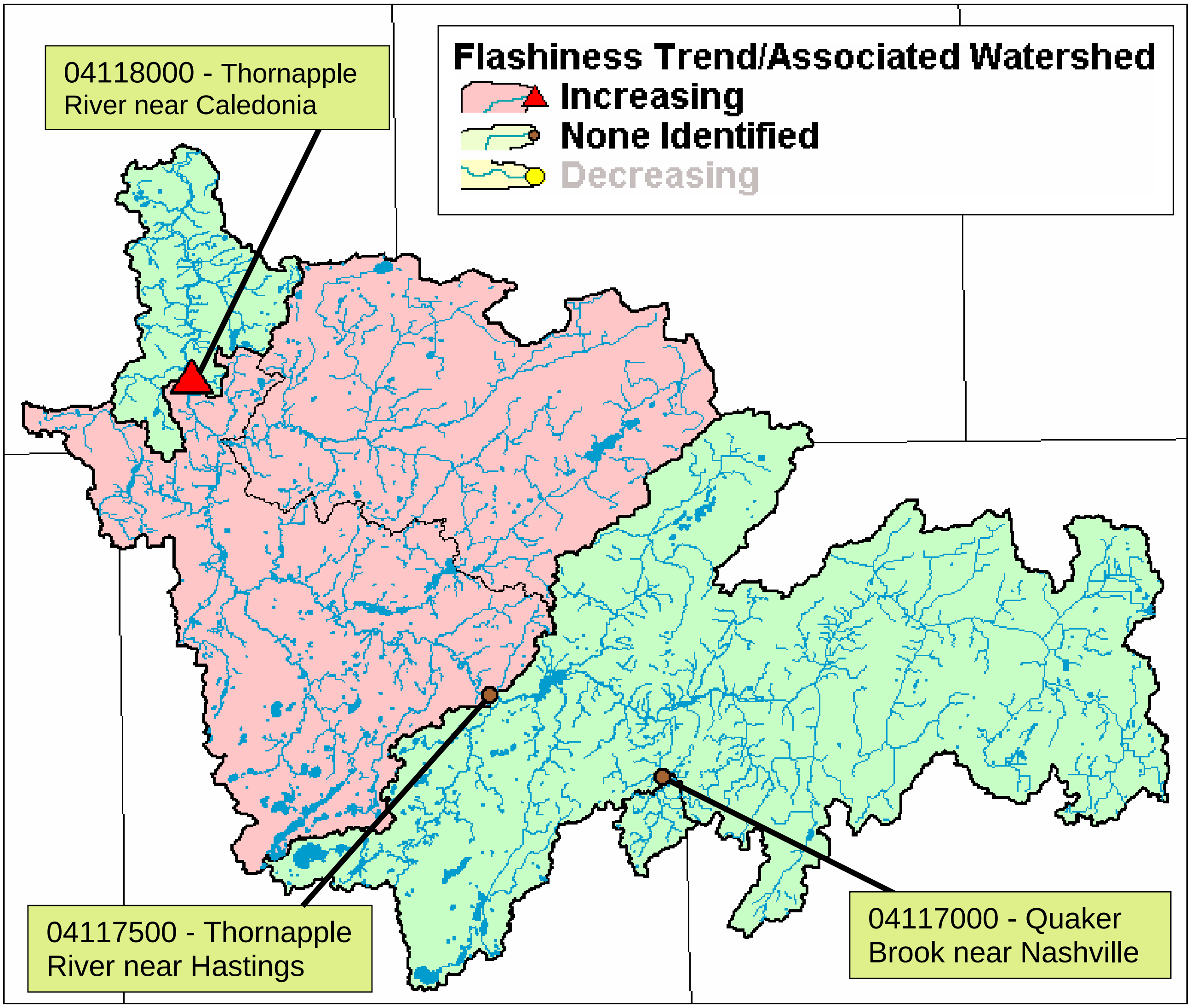


Figure 11 – Flashiness Trend by Gage, Thornapple River Watershed

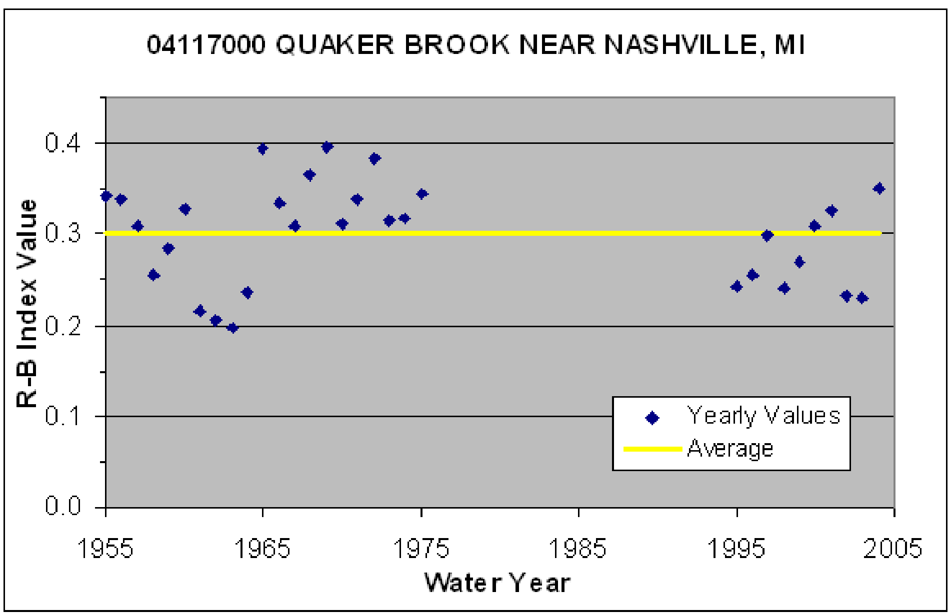
Gage Information

Graphs of the R-B Index values and trends for each gage are shown in Figures 12 through 14. The graphs are in numerical order. USGS gage stations are numbered in a downstream direction along the main stream. All stations on a tributary entering upstream from a main-stream station are listed before that station. A station on a tributary entering between two mainstream stations is listed between those stations.

The R-B Index value average is shown as a horizontal yellow line spanning the years used to calculate the average. If there is a statistically significant (i.e., $p < 0.10$) trend encompassing at least part of the past 25 years, it is represented by a sloped purple line. If a statistically significant trend change occurred, only the more recent trend is shown, and the R-B Index value average is based only on the years since that change.

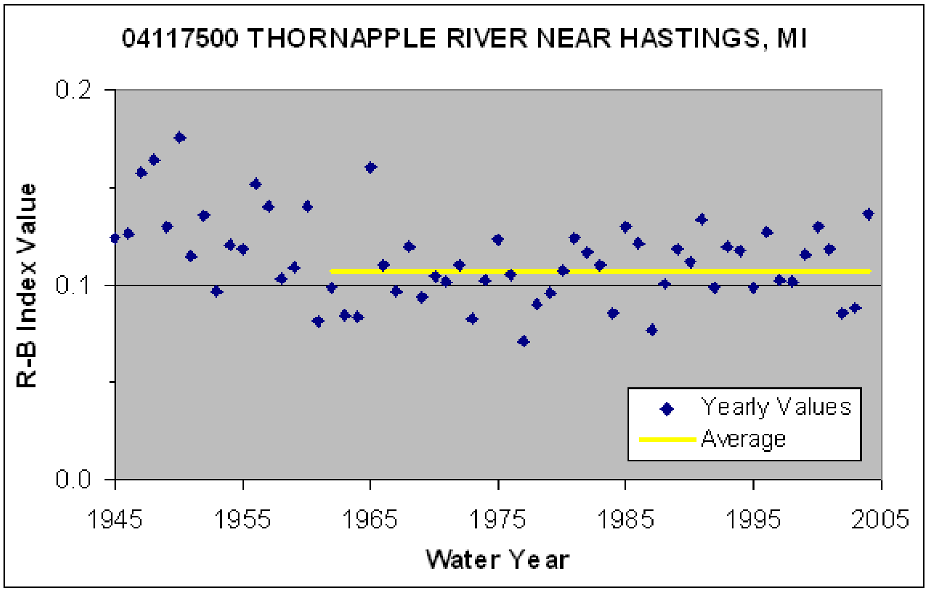
The x-axis always ends at 2005 so that the age of the data is more readily apparent. The y-axis is constrained to show gridlines for every 0.1 increment, allowing a sense of rank relative to other gages - more gridlines equate to higher values.

R-B flashiness statistical details and gage-specific information follow each graph. Statistical significance is based on the flashiness trend regression 'p' value. A 'p' value of 0.05 or less equates to 95 percent statistical significance. A 'p' value of 0.10 or less equates to 90 percent statistical significance. Total water years may be less than the ending water year minus the starting water year because of data gaps. Some gages that may be affected by dam operations are noted, but the listing may be incomplete.



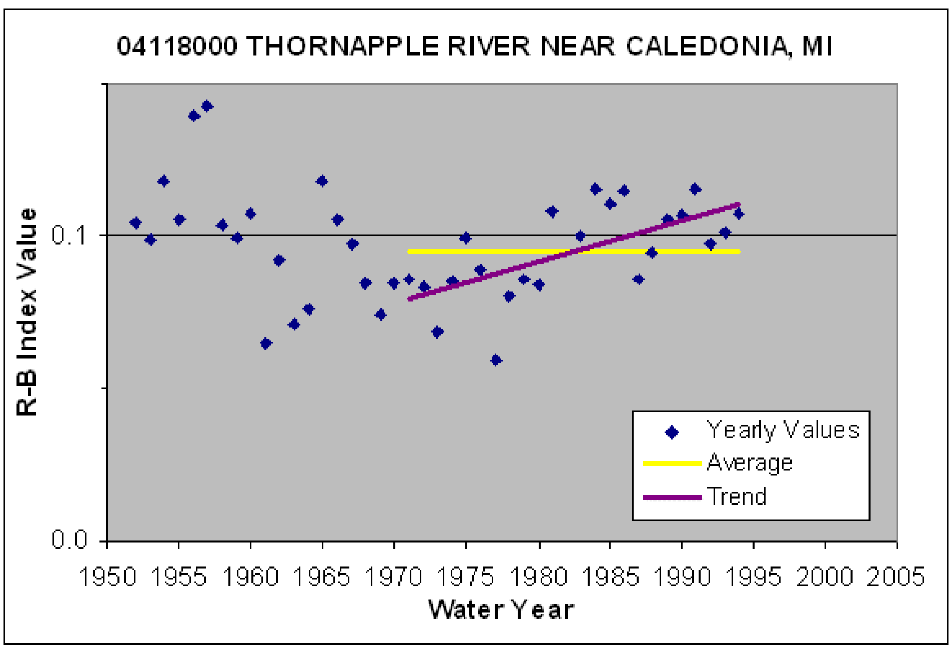
Total Drainage Area: 8 square miles Average R-B Index Value: 0.300 Rank: Lower middle Trend: none	First Water Year of Record/Analyzed: 1955 Last Water Year: 2004 Number of Years Analyzed: 31

Figure 12 – USGS Gage 04117000 – Quaker Brook near Nashville



Total Drainage Area: 410 square miles Average R-B Index Value: 0.107 Rank: Lower middle Trend: none	First Water Year of Record: 1945 First Water Year Analyzed: 1962 Last Water Year: 2004 Number of Years Analyzed: 43

Figure 13 – USGS Gage 04117500 – Thornapple River near Hastings



Total Drainage Area: 795 square miles Average R-B Index Value: 0.095 Rank: Lower middle Trend: more flashy	First Water Year of Record: 1952 First Water Year Analyzed: 1971 Last Water Year: 1994 Number of Years Analyzed: 24 p Value: <0.005
Notes: Prior to December 1958 and since October 1983, large diurnal fluctuation at low and medium flow and occasional regulation during high flow, caused by power plant upstream from station; occasional fluctuation during the interim period.	

Figure 14 – USGS Gage 04118000 – Thornapple River near Caledonia

Stream Morphology

Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades (fills in) nor degrades (erodes). A stable stream is in dynamic equilibrium, defined as “an open system in a steady state in which there is a continuous inflow and output of materials, in which the form or character of the system remains unchanged.” (Rosgen, 2006).

Stream stability is often depicted as a balance between sediment load, sediment size, stream slope, and stream discharge, Figure 15. The stream morphology will adapt so that the left side of the equation in Figure 15 balances the right side. An increase in discharge, especially channel-forming flows, increases the stream’s ability to move larger stone and soil particles, and promotes increased channel meandering and lateral bank erosion as the channel attempts to decrease its slope and enlarge its channel to restore balance.

Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural. An unstable stream is characterized by excessive, extensive erosion, with surplus sediment accumulating downstream, typically near the stream’s mouth or in a lake.

Simon (1989) defined six stages of channel evolution, Table 2. The stages describe a stream’s erosive evolution, starting with a stable channel (stage I) and ending with a refilled channel (stage VI). In between, the stream is disturbed by urbanization, forest clearing, dam construction, etc.

Table 2 – Stages of Channel Evolution

Stage	Stream Condition
I	Stream is stable.
II	Watershed’s hydrologic characteristics change – forest clearing, urbanization, dam construction, channel dredging, etc.
III	Channel instability sets in with scouring of the bed.
IV	Bank erosion and channel widening occur.
V	Banks continue to cave into the stream, widening the channel. The stream also accumulates sediment from upstream erosion.
VI	Re-equilibrium occurs and bank erosion ceases. Riparian vegetation becomes established.

Future hydrologic changes can further impact stream morphology, as well as water quality. These changes can be moderated with effective stormwater management techniques, such as treatment of the “first flush” runoff, wetland protection, retention and infiltration of excess runoff, low impact development techniques, 24-hour extended detention of 1-year flows, and properly designed detention of runoff from low probability storms. Refer to the Stormwater Management section for more detail.

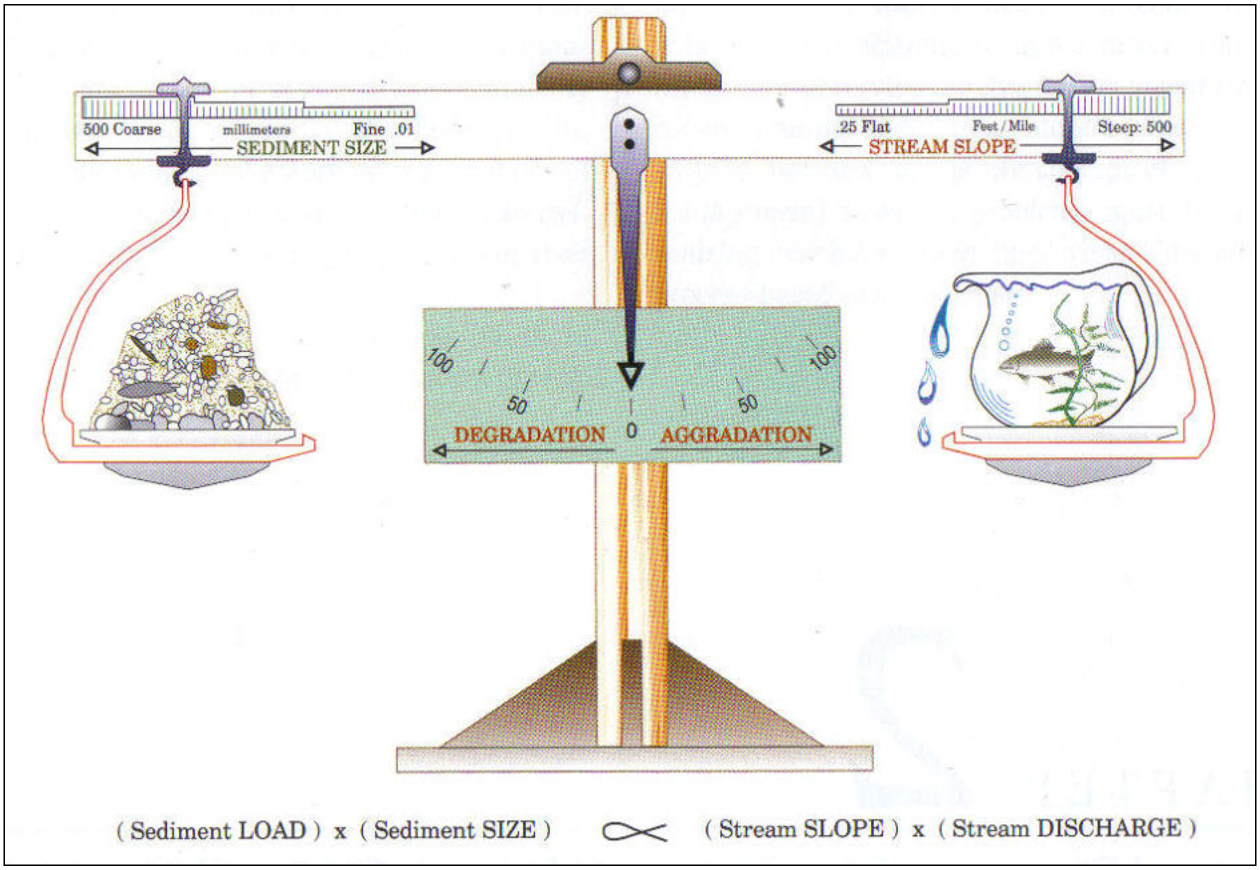


Figure 15 – Generalized Stable Channel Relationship proposed by Lane in 1955 (illustration from Rosgen 1996)

Recommendations

A river or stream is affected by everything in its watershed, although the stream will continue to exhibit morphologic adaptations to hydrologic changes long after the hydrologic changes are complete.

The Thornapple River flashiness analysis does not show any recent flow changes or increased flashiness other than that caused by the operation of a power plant. Although the flow regime appears to be currently stable, it is possible that the Thornapple River's morphology continues to adapt to past hydrologic changes. There may also be some local channel instabilities in more sensitive headwater streams due to nearby land use transitions or other local causes. Flow increases due to projected urbanization may be of concern if not properly managed, however.

Stormwater Management

When precipitation falls, it can infiltrate into the ground, evapotranspirate back into the air, or run off the ground surface to a water body. It is helpful to consider three principal runoff effects: water quality, channel shape, and flood levels, as shown in Figure 16.

Figure 16 – Runoff Impacts

Land use changes that reduce evapotranspiration and infiltration increase runoff. One reason low impact development has become more popular is that it avoids creating more runoff; intercepting and infiltrating the excess runoff instead.

Runoff from small rainfall events and the first portion of the runoff from larger events is termed the “first flush”, because it carries the majority of the pollutants. For more information, refer to the Water Quality section.

Larger, but frequent, storms or snowmelts produce the flows that shape the channel. These relatively modest storm flows, because of their higher frequency, have more effect on channel form than extreme flood flows. Hydrologic changes that increase this flow can cause the stream channel to become unstable. Stormwater management techniques used to mitigate flooding can also help mitigate projected channel-forming flow increases. However, channel-forming flow criteria should be specifically considered in the stormwater management plan so that the selected BMPs will be most effective. For example, detention ponds designed to control runoff from the 4 percent chance, 24-hour storm may do little to control the runoff from the 50 percent chance, 24-hour storm, unless the outlet is specifically designed to do so. For more information, refer to the Stream Channel Protection section.

Increases in the runoff volume and peak flow from large storms, such as the 4 percent chance (25-year), 24-hour storm, could cause or aggravate flooding problems unless mitigated using effective stormwater management techniques. For more information, refer to the Flood Protection section.

Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 17 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first flush." Some of the pollutants can settle out before discharging to a stream if this first flush runoff is detained for a period of time. Filtering systems are also used at some sites to treat the first flush stormwater.

Nationally, the amount of runoff recommended for capture and treatment varies from 0.5 inch per impervious acre to the runoff from a 50 percent chance storm. Michigan BMP guidelines recommend capture and treatment of 0.5 inches of runoff from a single site (Guidebook of Best Management Practices for Michigan Watersheds, 1998). The runoff is then released over 24 to 48 hours or is allowed to infiltrate into the ground within 72 hours. Dry detention ponds are less effective than retention or wet detention ponds, because the accumulated sediment in a dry detention pond may be easily resuspended by the next storm (Schueler, 2000).

Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. For multiple sites or watershed wide design, it is best to design to capture and treat 90 percent of runoff-producing storms. This "90 percent rule" effectively treats storm runoff that could be reaching the treatment at different times during the storm event. It was designed to provide the greatest amount of treatment that is economically feasible. In Michigan, values calculated for these storms range from 0.77 to 1.00 inches. For the Thornapple River watershed climatic regions, the calculated value is 0.90 to 1.00 inches. Additional information is available at www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf.

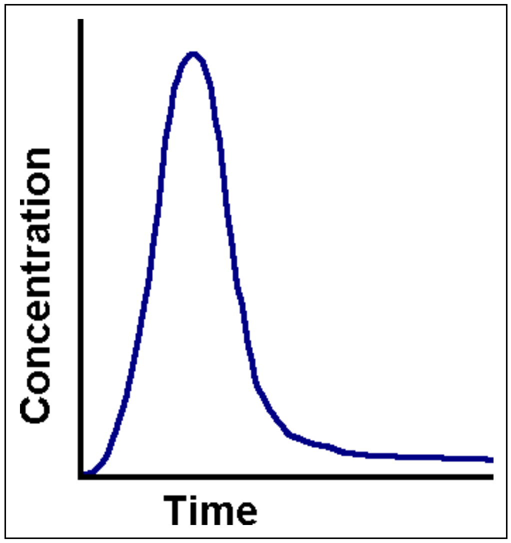


Figure 17 – Plot of Pollutant Concentration versus Time

Stream Channel Protection

A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades or degrades. Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural.

Possible causes of erosion are:

- Natural river dynamics
- Sparse vegetative cover due to too much animal or human traffic
- Concentrated runoff adjacent to the streambank, i.e. gullies, seepage
- In-stream flow obstructions, i.e. log jams, failed bridge supports
- An infrequent event, such as an ice jam or low probability flood
- Unusually large or frequent wave action
- A significant change in the hydrologic characteristics (typically land use) of the watershed
- A change in the stream form impacting adjacent portions of the stream, i.e. dredging, channelization

An assessment of the cause(s) of erosion is necessary so that proposed solutions will be permanent and do not simply move the erosion problem to another location. The first six listed causes can produce localized erosion. Either of the last two causes, however, could produce a morphologically unstable stream. Symptoms of active channel enlargement in an unstable stream include:

- Down-cutting of the channel bottom
- Extensive and excessive erosion of the stream banks
- Erosion on the inside bank of channel bends
- Evidence in the streambanks of bed erosion down through an armor layer
- Exposed sanitary or storm sewers that were initially installed under the steam bed

Erosion in a morphologically unstable stream is caused by increases in the relatively frequent channel-forming flows that, because of their higher frequency, have more effect on channel form than extreme flood flows. As shown in Figure 18, multiplying the sediment transport rate curve (a) by the storm frequency of occurrence curve (b) yields a curve (c) that, at its peak, indicates the flow that moves most of the sediment in a stream. This flow is termed the effective discharge. The effective discharge usually has a one- to two-year recurrence interval and is the dominant channel-forming flow in a stable stream.

Increases in the frequency, duration, and magnitude of these flows cause stream bank and bed erosion as the stream adapts. According to the *Stream Corridor Restoration* manual, stream channels can often enlarge their cross-sectional area by a factor of 2 to 5 (FISRWG, 10/1998). In *Dynamics of Urban Stream Channel Enlargement, The Practice of Watershed Protection*, ultimate channel enlargement ratios of up to approximately 10 are reported, as shown in Figure 19 (Schueler and Holland, 2000). To prevent or minimize this erosion, watershed stakeholders should specifically consider stormwater management to protect channel morphology. Low impact development and infiltration BMPs can be incorporated to offset flow increases. Stormwater management ordinances can specifically address channel protection. However, where ordinances have included channel protection criteria, it has typically been focused on controlling peak flows from the 2-year storm.

The nationally recognized Center for Watershed Protection asserts that 24-hour extended detention for runoff from 1-year storms better protects channel morphology than 2-year peak discharge control because it does not reduce the frequency of erosive bankfull and sub-bankfull flows that often increase as development occurs within the watershed. Indeed, it may actually increase the duration of these erosive, channel-forming flows. The intent of 24-hour extended detention for runoff from 1-year storms is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 20. A few watershed plans funded through the MDEQ Nonpoint Source Program have recommended requirements based on this criterion. One such example is from the Anchor Bay Technical Report (2006) and is shown in Figure 21. This analysis, which is for climatic region 10, is for 2.06 inches of rainfall. The Thornapple River watershed is mostly in climatic region 8, which has a 50 percent chance (2-year) 24-hour storm design rainfall value of 2.37 inches, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. The MDEQ Nonpoint Source Program is funding this analysis for western Michigan through the Lower Grand Initiatives grant, 2007-0137, to the Grand Valley Metropolitan Council.

Detention designed to control channel-forming flows and prevent streambank erosion may not be needed for runoff routed from a city through storm sewers to a large river simply because the runoff routed through the storm sewers enters the river well ahead of the peak flow in the river. In this case, the management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

Hydrologic and hydraulic modeling may be justified to determine if runoff from a drainage area should be limited, either by detention or infiltration, to prevent flow or flood level increases or to verify that flood peaks are not increased due to the timing of the peak flows from detention ponds and in the stream. Thornapple River watershed stakeholders may elect to recommend some conditions when detention or retention for channel protection is not necessary. For example, the watershed stakeholders may adopt a watershed plan that calls for channel protection measures, unless runoff discharges from a storm drain directly to a large river.

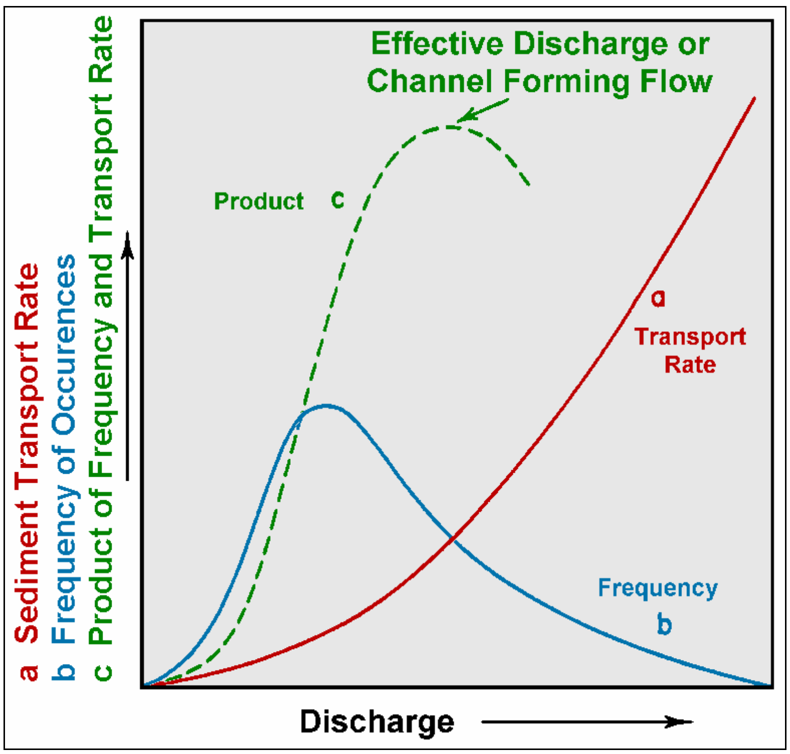


Figure 18 – Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

sewers enters the river well ahead of the peak flow in the river. In this case, the management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

Hydrologic and hydraulic modeling may be justified to determine if runoff from a drainage area should be limited, either by detention or infiltration, to prevent flow or flood level increases or to verify that flood peaks are not increased due to the timing of the peak flows from detention ponds and in the stream. Thornapple River watershed stakeholders may elect to recommend some conditions when detention or retention for channel protection is not necessary. For example, the watershed stakeholders may adopt a watershed plan that calls for channel protection measures, unless runoff discharges from a storm drain directly to a large river.

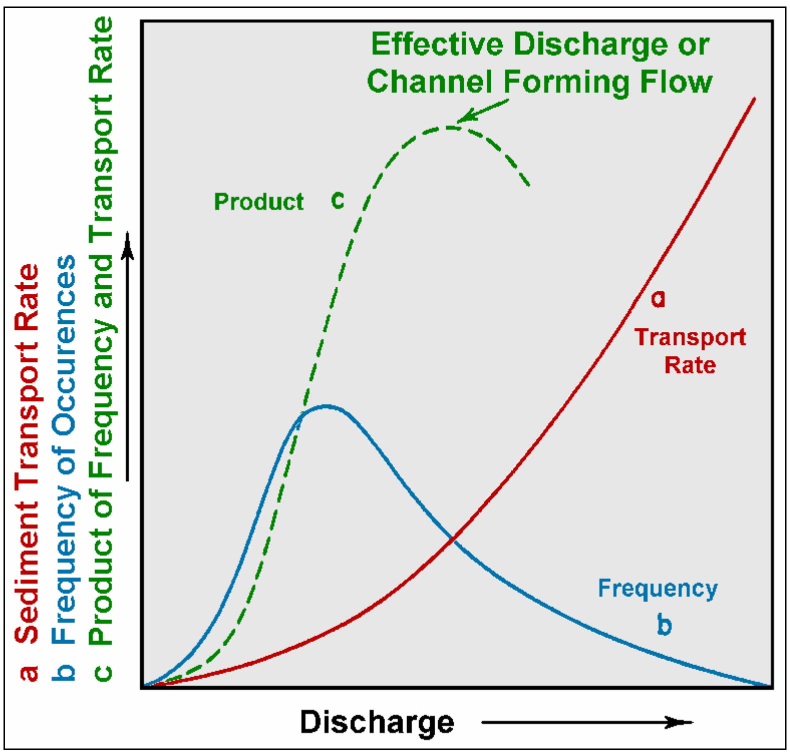


Figure 18 – Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

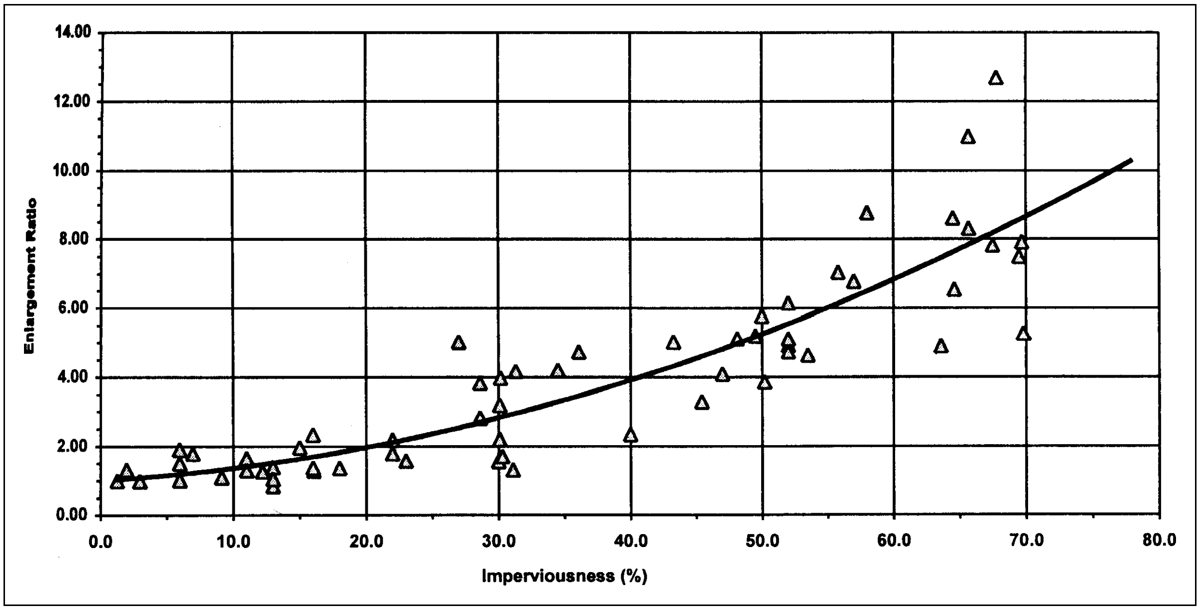


Figure 19 – "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

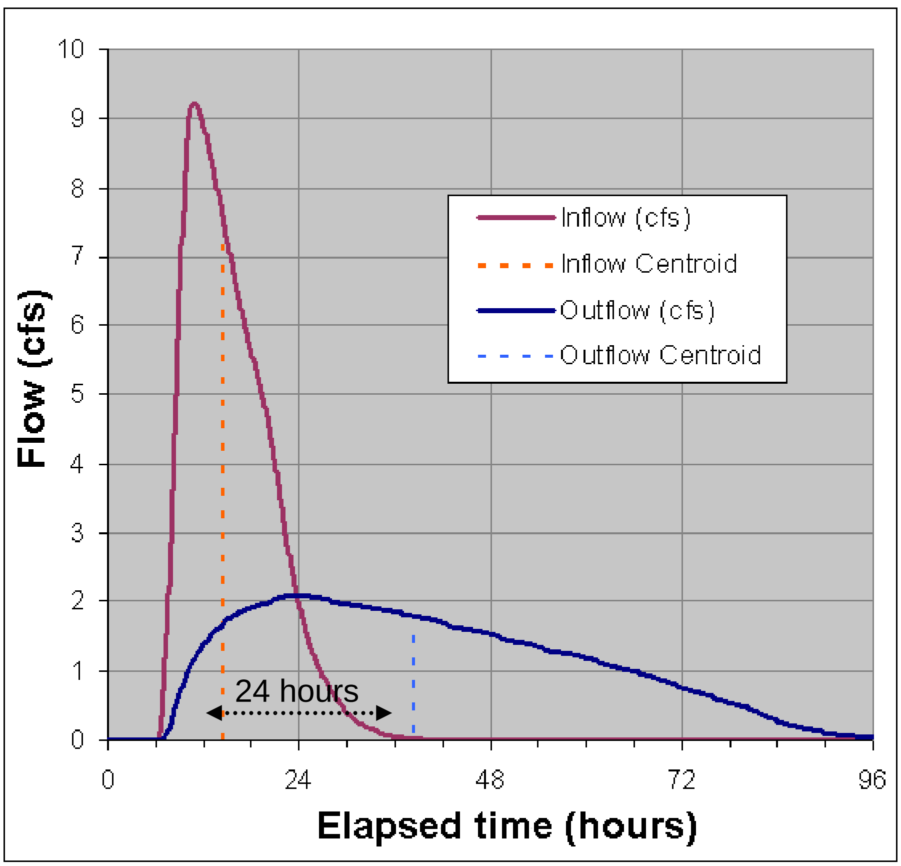


Figure 20 – Example of 24-hour extended detention criterion applied to detention pond design

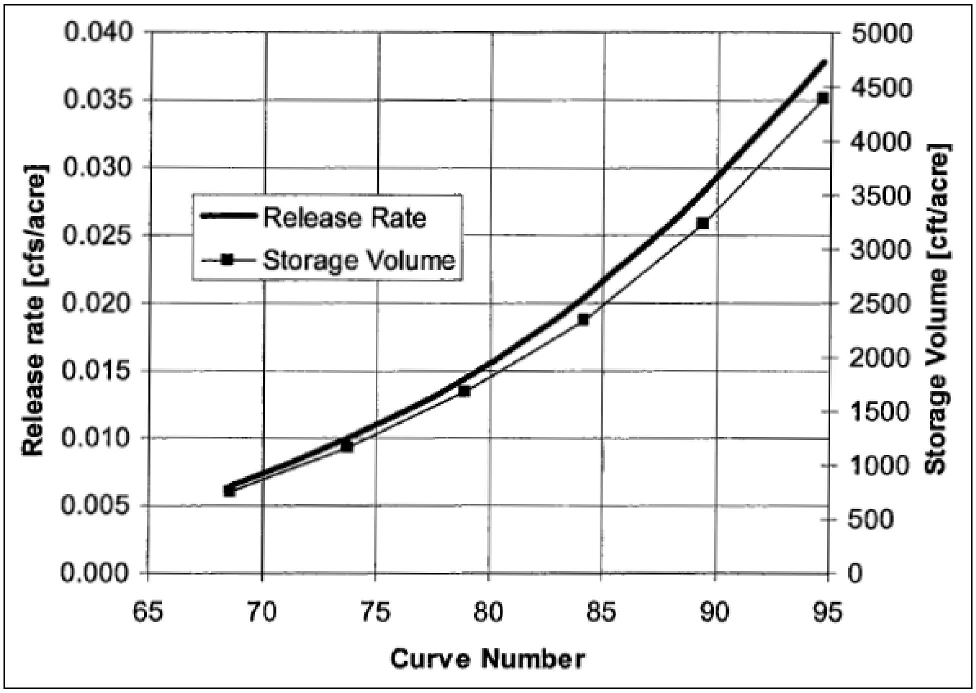


Figure 21 – Example of detention pond requirements derived from the 24-hour extended detention criterion

Flood Protection

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions and putting people, homes, and other structures at risk. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

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